Heart Rate Response During Underwater Treadmill Training in Adults with Incomplete Spinal Cord Injury

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Background: Walking on a submerged treadmill can improve mobility in persons displaying lower limb muscle weakness and balance deficits. Little is known, however, regarding the effect of water treadmill exercise on cardiac performance in persons with incomplete spinal cord injury (iSCI). **Objective:** To assess heart rate response during underwater treadmill training (UTT) in adults with iSCI. **Methods:** Seven males and 4 females with iSCI (age = 48 ± 13 years; 5 ± 8 years after injury) completed 8 weeks of UTT (3 sessions per week; 3 walks per session) incorporating individually determined walking speeds, personalized levels of body weight unloading, and gradual, alternating increases in speed and duration. Heart rate was monitored during the last 15 seconds of the final 2 minutes of each walk. **Results:** Over the course of 3 biweekly periods in which walking speed remained constant, heart rate fell by 7% (7 ± 1 b•min^{-1}; $P < .001$) in weeks 2 and 3, 14% (17 ± 6 b•min^{-1}; $P < .001$) in weeks 4 and 5, and 17% (21 ± 11 b•min^{-1}; $P < .001$) in weeks 6 and 7. **Conclusion:** In adults with iSCI, progressively greater absolute and relative reductions in submaximal exercise heart rate occurred after 2 months of UTT featuring a systematic increase in training volume. **Key words:** *gait training, heart rate response, spinal cord injury, underwater treadmill*

Reduced levels of physical activity and daily energy expenditure contribute to the increased risk of coronary heart disease in adults with spinal cord injury (SCI).[1,2] Because health variables commonly associated with cardiovascular disease (eg, obesity, diabetes, sedentary living) tend to be more prevalent in individuals with SCI compared to persons displaying normal locomotor profiles,[1] positive modification of these risk factors may substantially reduce mortality in this clinical population.[3] However, given the presence of autonomic dysfunction and loss of motor function with SCI, achieving adequate levels of physical activity in this population can be challenging.[2]

During physical activity, withdrawal of vagal tone and activation of the sympathetic nervous system normally cause an increase in heart rate and oxygen consumption.[4,5] During submaximal exercise in able-bodied individuals, stimulation of the sympathetic nervous system via central command produces an increase in heart rate that is linearly correlated with oxygen uptake. Conversely, disruption of descending neural pathways in persons with SCI can lead to sympathetic hypoactivity and unopposed parasympathetic control, resulting in reflex bradycardia, low resting blood pressure, orthostatic hypotension, and loss of cardiac adaptability during physical activity.[6-8] These pathological responses are often present in cervical and thoracic injuries above the level of sympathetic outflow (ie, T5 and above) due to interference with communication between supraspinal control centers and sympathetic pathways to the heart.[8] Individuals with spinal cord lesions below the level of sympathetic outflow (ie, T6 and below) exhibit a markedly lower stroke volume and a higher resting heart rate compared to those without paraplegia.[6] This elevation in chronotrophic activity is thought to compensate for blood pooling in the lower extremities, diminished venous return, and reduced cardiac preload – a trio of physiological responses that reflect a suboptimal circulatory response to

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aerobic exercise.[6,7,9,10] Furthermore, compared to able-bodied persons, individuals with tetraplegia exhibit lower epinephrine and norepinephrine concentrations at rest and only a slight elevation in catecholamine levels during exercise, resulting in less cardiac sympathetic innervation and cardioacceleration and a marked decrease in maximal oxygen uptake.[6]

Despite limitations in cardiac response and endurance capacity in adults with SCI, participation in regular doses of physical activity has been shown to improve cardiovascular fitness, reduce the presence of chronic disease risk factors, and increase functional independence following SCI.[10-15] Among persons with SCI for whom arm function is spared, upper extremity exercise, a logical choice for improving aerobic function, does not adequately stress circulatory mechanisms to induce central adaptations to prolonged activity.[16,17] Consequently, physiological benefits derived from upper body exercise programs are primarily localized within the muscle groups that are trained.[18] Blood pooling in the legs is also present in persons with SCI due to reduced sympathetic tone and an absent or diminished lower extremity muscle pump, which can result in lower venous return and preload of the heart during arm exercise and a decreased potential to improve cardiovascular fitness and aerobic performance.[19,20] These limitations in performing upper body physical activity have spurred efforts to promote the use of lower limb exercise to increase aerobic fitness in persons with SCI.[21] However, current techniques designed to facilitate lower body physical activity, such as treadmill training with manual assistance, functional electrical stimulation during cycling, or powered gait orthotics and robotic training devices, often fail to achieve a level of cardiovascular stress recommended for persons with gait impairment and may interfere with long-term recovery by decreasing the activation of muscle responses associated with independent walking, thus muting potential training effects.[22-24]

A self-initiated form of gait therapy that has received little attention in the treatment and rehabilitation of individuals with SCI is underwater treadmill training (UTT). Walking on a treadmill submerged in water allows for the precise control of walking speed, water depth, and water temperature – a set of variables that can influence cardiorespiratory responses. The positive influence of hydrostatic pressure in elevating central blood volume facilitates venous return to the heart. Water-based treadmill exercise can also serve as an effective alternative to walking and exercise programs in persons with leg muscle weakness and balance deficits,[25,26] and the bouyant effects of water result in a more comfortable and realistic unloading of body mass than that provided by harnessing systems that feature point-specific unloading. In this regard, Stevens and colleagues[27] have reported increases in leg strength, balance, and walking ability in adults with incomplete SCI (iSCI) following 8 weeks of UTT.

Although limited evidence is available describing acute heart rate responses of persons with SCI walking in different orthoses[28] and during passive locomotion[29] and functional neuromuscular stimulation-assisted ambulation,[30] the impact of an aquatic walking program on cardiovacular response in individuals with neuromuscular disease has not been documented. Consequently, we sought to quantify changes in heart rate during UTT in adults with iSCI. Based on data showing that land-based endurance training leads to reductions in submaximal heart rate in healthy untrained persons,[31-34] we hypothesized that adults with iSCI who underwent UTT would display a similar response in heart rate.

Methods

Eleven adults with iSCI (7 males, 4 females) volunteered to participate in this study. Enrollment criteria included being at least 21 years of age, the absence of complex comorbidity, the ability to walk at least 10 meters with or without an assistive device, and being more than 1 year after injury. All volunteers were required to submit physician documentation of SCI and provide medical clearance prior to testing and UTT. Descriptive information for the participants is provided in **Table 1**. This study was approved by the university institutional review board, and participants provided informed written consent prior to data collection.

Table 1. Descriptive characteristics of study participants

Participant no.	Sex	Age, years	Level of lesion[a]	AIS[b]	Years after injury	WISCI-II[c]	Primary mode of locomotion
1	M	56	T5	C	3	9	Wheelchair
2	M	62	C4	D	2.5	16	Ambulation
3	M	62	L2	C	6	16	Wheelchair
4	F	51	C3	C	3	6	Ambulation
5	M	43	T8	C	2	9	Wheelchair
6	M	28	L2	C	28	18	Wheelchair
7	M	23	C6	C	1.5	16	Wheelchair
8	F	64	C4	C	1	13	Ambulation
9	M	50	C2	C	1	11	Wheelchair
10	F	40	T6	D	3	9	Wheelchair
11	F	46	L2	C	2	13	Wheelchair

Note: M = male; F = female.

[a]Level of lesion: C = cervical; T = thoracic; L = lumbar.

[b]AIS = American Spinal Injury Association Impairment Scale. C = incomplete: motor function is preserved below the neurological level, and more than half of key muscles below the neurological level have a muscle grade less than 3; D = incomplete: motor function is preserved below the neurological level, and at least half of key muscles below the neurological level have a muscle grade of 3 or more).

[c]WISCI = Walking Index for Spinal Cord Injury; range = 0 (inability to walk, even with maximum assistance) to 20 (ability to walk 10 meters without assistance or the use of a mobility device).

Preferred overground walking speed

Preferred overground walking speed was determined by having participants walk in a straight line for 14 meters at a normal, comfortable pace in an indoor gymnasium. Using 2 photoelectric cells, walking time was recorded during the central 10 meters of the course to account for potential acceleration and deceleration effects. Participants completed the test using assistive devices normally employed while walking in their natural environment. Each participant performed 3 walking trials and was allowed to rest for as long as needed between trials. From knowledge of distance and time, walking speed was calculated for each trial and averaged to derive freely chosen walking speed for each participant.

Treadmill accommodation

Prior to training, participants accommodated to walking on an underwater treadmill (Hydro Track Underwater Treadmill System; Conray Inc., Phoenix, AZ) submerged in a self-contained tank (see **Figure 1**). Each participant was fitted with a body harness worn loosely around the midsection of the body with no groin strap. Although the harness did not provide body weight support, it served to catch participants if they stumbled or slipped while walking on the treadmill. Upon entering the tank, participants stood while water height was adjusted to a level enabling attainment and maintenance of an upright position, with knees and hips in a maximally extended position during bilateral stance with no upper extremity support. The average level of body weight unloading, determined using a LiteGait BiSym Suspension System (Lite Gait, Tempe, AZ), was 38% of body weight (range, 30% to 47%), a value similar to that employed in other investigations of body weight–supported treadmill training.[35-37]

Once water height was established, each participant walked for 1 minute at a speed that was 50% slower than their preferred overground walking speed or at 0.20 $m \cdot s^{-1}$ (the slowest speed setting on the underwater treadmill), whichever was faster. If the water level allowed for an appropriate balance between support and loading during the 1-minute walking trial, it was used for all UTT sessions. After water height was

Figure 1. A participant walking on an underwater treadmill.

determined for each participant, three 5-minute walks were completed. Prior to walking, a Polar heart rate monitor (Polar Electro Inc., Lake Success, NY) was secured around the chest and transmitted an ongoing digital display of standing and exercise heart rate values to a watch that was affixed to the side of the underwater treadmill and was easily viewed by members of the research team. Participants were also asked to identify their rating of perceived exertion (RPE) using the Borg scale.[38] During the first walking trial, treadmill speed was gradually adjusted until an increase in heart rate above standing heart rate was observed, an RPE of at least 3 (moderate exertion) was reported, no adverse physical responses (eg, dizziness, changes in muscle tone, shortness of breath, pain) were noted, and appropriate levels of hip and knee extension were maintained. The final speed setting achieved during this initial exercise trial was used during the remaining accommodation walks and served as the training speed during the first week of UTT. Rest periods of at least 5 minutes were provided between walking trials.

For each participant, water temperature was set at 90°F during the first walking trial to assess the effect of water temperature on muscle tone. If a negative influence on mobility was observed (eg, facilitation of a crossed extension pattern interfering with stepping) or an adjustment in water temperature was requested by a participant to enhance comfort, modifications were made to address these concerns. Water temperature during the study remained constant unless a change was requested by the participant or adverse physiological reactions (eg, excessive sweating, abnormal rise in heart rate or RPE) were noted.

Underwater treadmill training

Following accommodation to underwater treadmill walking, participants completed 24 training sessions (3 sessions per week) over an 8-week period. This training schedule was chosen based on evidence suggesting that 8 weeks of land-based body weight–supported treadmill training is sufficient to produce measurable improvements in overground walking performance among individuals with iSCI.[35] Each training session featured 3 walking trials of equal duration at the water height, walking speed, and water temperature established for each participant during the treadmill accommodation session. In weeks 2, 4, 6, and 8, walking speed was increased by 10%, 20%, 30%, and 40%, respectively, over baseline (week 1) speed. All but one participant was able to tolerate scheduled biweekly increases in walking speed, and this person accommodated to speed changes varying from 5% to 10%. The duration of each walk, initially set at 5 minutes during the first 2 weeks of UTT, was also lengthened by 1 minute in weeks 3, 5, and 7, resulting in an overall increase in exercise duration of 3 minutes per training session every 2 weeks. Hence, at the start of training (weeks 1 and 2), participants completed three 5-minute walks and accumulated 15 minutes of walking. However, by the last 2 weeks of training (weeks 7 and 8), all participants were able to perform three 8-minute walks for a total of 24 minutes of walking, resulting in a 60% increase in total

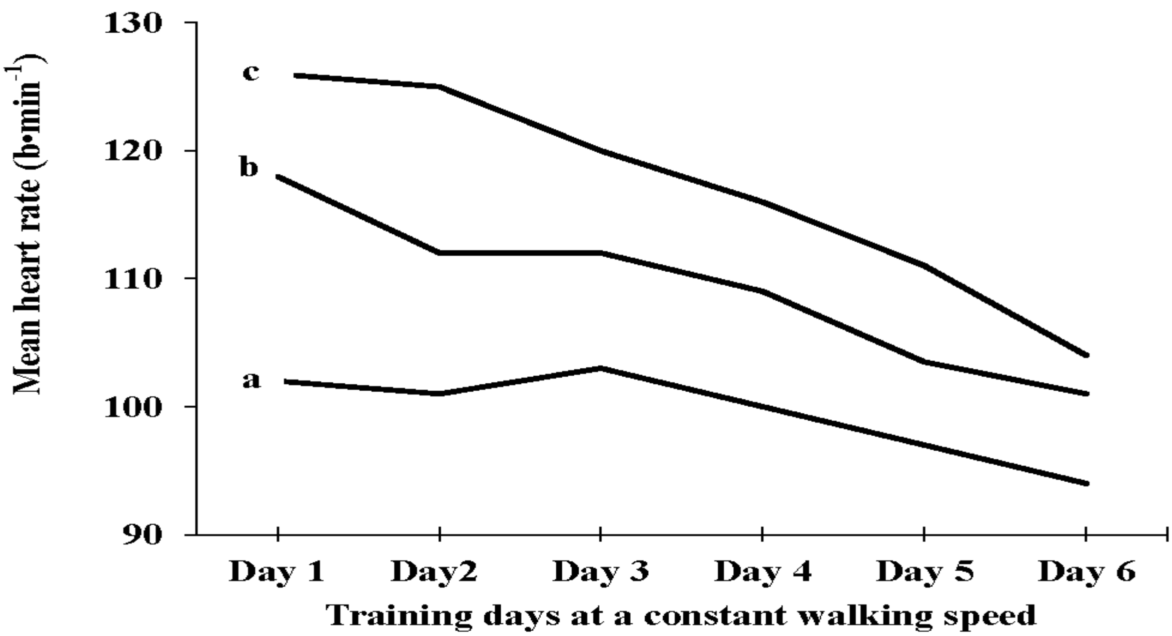

Figure 2. Mean heart rates during (a) weeks 2 and 3, (b) weeks 4 and 5, and (c) weeks 6 and 7 of underwater treadmill training. Participants performed 3 days of training per week; training days 1, 2, and 3 occurred during weeks 2, 4, and 6 and training days 4, 5, and 6 occurred during weeks 3, 5, and 7. Walking speeds for (a), (b), and (c) were 10%, 20%, and 30% faster than week 1 speed, respectively.

exercise duration. Digital readings of exercise heart rate transmitted from the chest-worn monitor during the last 15 seconds of the final 2 minutes of each walk were averaged to determine mean exercise heart rate for a given walking trial. During each 15-second period, a heart rate value was recorded manually every second, resulting in 30 heart rate values for each of the 3 walks completed in a given UTT session. A minimum of 5 minutes of rest was provided between walking trials.

Data analysis

Mean heart rate values calculated for the 3 walks performed during each training session were averaged to derive a mean heart rate for each day of UTT. Injury level was stratified based on injuries occurring at or above T5 ($n = 6$) or below T5 ($n = 5$). A 3-factor, repeated measures analysis of variance (ANOVA) (day, training period, injury level) was conducted to assess changes in mean heart rate values obtained between the first (day 1) and last (day 6) days of UTT for each 2-week training period (training period 1, weeks 2 and 3; training period 2, weeks 4 and 5; training period 3, weeks 6 and 7) in which walking speed remained constant. Interaction contrasts were conducted if a significant interaction was detected. A familywise alpha of .05 was used for all tests.

Results

Table 2 presents individual and mean heart rate data for the first (day 1) and last (day 6) training days for training periods 1, 2, and 3, while **Figure 2** portrays daily changes in average exercise heart rate values for each 2-week time block. Findings from the ANOVA tests (with Hyunh-Feldt adjusted P values) revealed that none of the interaction tests involving injury level were statistically significant [injury level, $F(1, 10) = 1.54$, $P = .25$; Training Period x Injury Level, $F(1, 10) = 1.14$, $P = .34$; Day x Injury Level, $F(1, 10) = 4.65$, $P = .06$; Training Period x Injury Level x Day, $F(1, 10) = 1.04$, $P = .35$]. When averaged over injury level, the interaction between training period and day

Table 2. Individual mean heart rate responses to underwater treadmill training during training periods 1 (weeks 2 and 3), 2 (weeks 4 and 5), and 3 (weeks 6 and 7)

Participant no.	Training period 1				Training period 2				Training period 3			
	Day 1	Day 6	Δ	Δ%	Day 1	Day 6	Δ	Δ%	Day 1	Day 6	Δ	Δ%
1	115	107	7	6	120	107	13	11	123	107	16	13
2	100	94	6	6	126	103	23	18	121	103	s	8
3	113	106	7	6	119	102	17	14	122	106	16	13
4	111	104	7	6	118	104	14	12	122	105	17	14
5	98	91	7	7	124	101	23	19	119	109	10	8
6	93	83	10	11	108	98	10	9	138	99	39	28
7	95	86	9	9	110	101	9	8	134	101	33	25
8	99	93	6	6	125	102	23	18	120	110	10	8
9	94	85	9	10	109	99	10	9	135	100	35	26
10	110	103	7	6	117	100	17	15	131	98	33	25
11	97	91	6	6	123	97	26	21	121	104	17	14
Grand mean	102	95	7	7	118	101	17	14	126	105	21	17

Note: Heart rate is given in beats per minute. Training period 1: weeks 2 and 3; training period 2: weeks 4 and 5; training period 3: weeks 6 and 7. Walking speed during training period 1 = 10% faster than week 1 speed; walking speed during training period 2 = 20% faster than week 1 speed; walking speed during training period 3 = 30% faster than week 1 speed. Δ = difference in mean heart rate from day 1 to day 6 during each 2-week training period. %Δ = percent difference in mean heart rate from day 1 to day 6 during each 2-week training period.

was statistically significant, $F(1, 10) = 7.89$, $P = .01$. Pairwise comparisons revealed that from day 1 to day 6, heart rate fell by 7% (7 ± 1 b•min^{-1}, $t = 18.14$, $P < .001$), 14% (17 ± 6 b•min^{-1}, $t = 8.97$, $P < .001$), and 17% (21 ± 11 b•min^{-1}, $t = 6.43$, $P < .001$) during training periods 1, 2, and 3, respectively. In addition, as noted in **Table 2**, all 11 participants exhibited decreases in daily walking heart rate for each 2-week period.

Discussion

Results from our study demonstrate that self-initiated underwater treadmill training performed 3 times a week for 8 weeks provides the necessary cardiovascular strain to improve walking performance and reduce walking heart rate in persons with iSCI. Specifically, a mean decrease in heart rate of 15 b•min^{-1} was observed while walking speed and exercise duration were progressively increased. This level of improvement in cardiac performance is similar to land-based heart rate responses to endurance training (12 to 15 b•min^{-1}) measured in sedentary, disease-free individuals,[31] and every study participant exhibited a reduction in chronotropic activity. The absolute and relative magnitude of the training-related decrease in walking heart rate was also more pronounced at faster walking speeds and longer walking durations (ie, increased training volumes), a finding that comports with the observation that training-induced reductions in submaximal heart rate measured while performing land-based exercise are magnified at higher intensities.[39] Moreover, in our limited sample of participants with iSCI, training-related changes in walking heart rate were not significantly affected by level of injury. A particularly striking example of the impact of UTT on cardiac activity during water treadmill walking was observed when mean heart rate values during weeks 4 through 7 were compared. As shown in **Figure 2**, group values for heart rate measured on the final 2 days of weeks 6 and 7 (days 5 and 6 of line c) were actually lower than heart rate values recorded during all of week 4 (days 1, 2, and 3 of line b), even though the overall training volume (walking speed x walking duration) was greater in week 7 compared to week 4.

With regard to potential mechanisms associated with the decrease in submaximal heart rate produced by UTT, exercise bradycardia is generally thought to reflect a shift in the balance of autonomic tone between sympathetic cardiac accelerator activity and parasympathetic depressor activity toward vagal dominance.[40] This bias toward parasympathetic tone and reduced sympathetic neural discharge is accompanied by peripheral adaptations that improve aerobic performance, such as greater dilation of local resistance vessels within cardiac and skeletal muscle and elevated muscle oxidative function.[31] In addition, greater muscle activity linked to the gradual rise in total exercise volume during UTT would enhance muscle pump activity and result in a higher stroke volume. Maximum stroke volume typically occurs at 40% to 50% of maximal oxygen uptake[31,41] and at moderate exercise intensities typically associated with the range of average exercise heart rate values recorded for most participants in the middle and latter stages of UTT.[31,42]

While few studies have documented training-related adjustments in exercise heart rate in persons with SCI, Ditor and colleagues[43] measured changes in exercise heart rate in 8 adults with iSCI following participation in a 3-day-a-week, land-based, partial body weight–supported treadmill training program lasting 6 months. Data from their study revealed that mean heart rate values during the first and last 3 months of body weight–supported treadmill training were 129 and 126 bpm, respectively. This decline of 2% in walking heart rate occurred while body weight support was reduced and speed and duration were increased. In contrast, findings from the current project revealed a mean decrease of 17% in heart rate during the final 2 weeks of UTT and an average reduction in heart rate of 13% across the entire 2-month training period during which substantial increases in walking intensity and duration were imposed as the study progressed. Given these results, it seems reasonable to suggest that substantive improvements in cardiac and locomotor performance observed in our sample of adults with iSCI were tied to participation in a water-based, ambulatory training program that facilitated increases in venous return and cardiac output while allowing training-induced reductions in heart rate to occur and longer, more intense walking trials to be completed as training progressed.[39] Although speculative, decreases in submaximal heart rate with UTT may have also reflected a lower metabolic energy expenditure associated with less extraneous and energy-wasteful movement.[39] Along these lines, Kressler and colleagues[44] have reported that treadmill locomotor training with transcutaneous electrical stimulation (TS) and overground locomotor training with TS yielded a reduction in the aerobic demand of walking in individuals with chronic motor-incomplete SCI when compared to treadmill locomotor training with manual assistance or a gait-driven orthosis.

Conclusions

Data from our investigation show that in adults with iSCI, UTT results in a significant decrease in submaximal exercise heart rate that mimics chronotropic adaptations experienced by sedentary, able-bodied adults engaged in walking programs performed on land. Given these findings, additional research featuring larger sample sizes should be conducted to quantify differences in cardiac response between UTT and traditional partial body weight–supported treadmill training and document the potential impact of UTT on land-based walking economy. As the primary goal of overground gait training is to improve ambulation, future studies should also be performed to compare changes in cardiovascular fitness and mobility outcomes following water-based treadmill training.

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The authors declare no conflicts of interest.

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